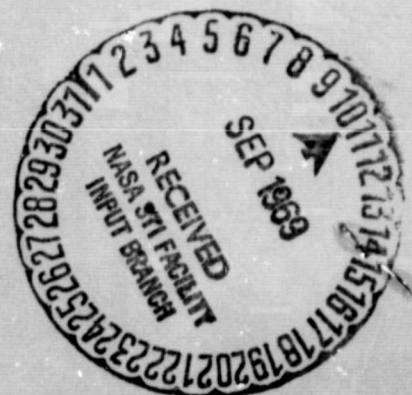
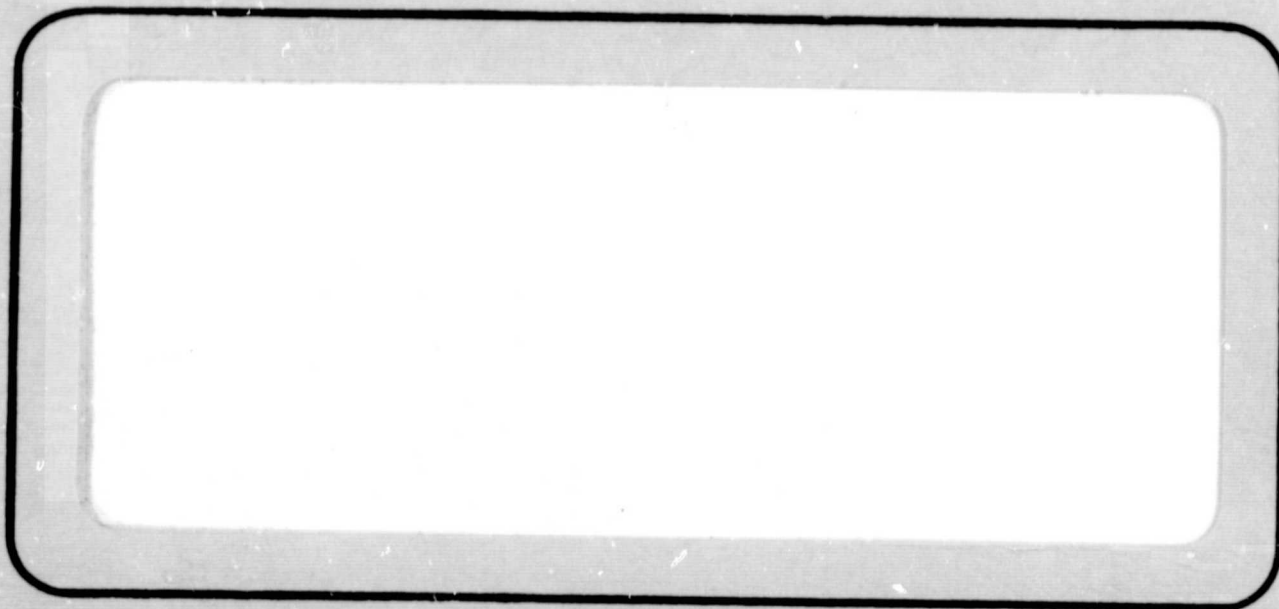


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TRW
SYSTEMS GROUP

ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

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First Quarterly Progress Report
THROTTLEABLE THRUSTOR SYSTEM

JPL Contract No. 952344

Report No. 69.4726.3-64

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TRW SYSTEMS

One Space Park • Redondo Beach, California

ABSTRACT

The first phase of the Throttleable Thrustor System contract consists of a Study and Analysis of various systems capable of meeting specified requirements. Initially, design goals for the system and potential approaches toward achievement of these goals were listed. Advantages and disadvantages of these approaches were compared and used to compile a matrix of possible system designs. These designs were compared on the basis of mission performance, concept feasibility, required development and alternate approach representation. Nine candidate design concepts were selected for the remainder of the study. Ground rules for the balance of Phase I were defined. Three type of studies are to be accomplished: system performance, flow control tradeoffs and preliminary design. Effort was initiated in each of these areas.

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I. INTRODUCTION

The simplicity and demonstrated reliability of monopropellant hydrazine propulsion systems has fostered their use on ever more ambitious missions. In addition, since the flow of a single propellant only must be regulated, throttling may be easily accomplished. These factors have led to the consideration of hydrazine systems for increasingly complex missions such as Voyager and Viking class planetary landers.

The objective of the Throttleable Thrustor System contract is therefore to advance the state-of-the-art of hi-thrust throttleable monopropellant hydrazine thrustor systems. To this end, a three phase program is being accomplished by TRW Systems Group as follows:

- Phase I Study and analysis, and comparison of different mechanizations capable of meeting stipulated performance requirements.
- Phase II Detailed design of the candidate system selected as a result of the Phase I study.
- Phase III Fabrication and test verification of the performance and response characteristics of the selected configuration.

This report is the first quarterly report for the subject contract covering the initial portion of Phase I from contract initiation through the end of the second quarter of CY 1969.

II. TECHNICAL DISCUSSION

The initial task accomplished during Phase I was the selection of the candidate systems to be studied during the balance of Phase I. The considerations and rationale for this process are summarized below in Section A and will be discussed in detail in the next Quarterly Report. A brief description of the type of studies which will comprise the balance of Phase I is presented in paragraph B below.

A. Design Concept Selection

Design goals for the throttleable thruster system and potential approaches toward achievement of these goals were listed. This listing was used as a guide to prepare a compilation of possible designs for each of the components in the system; namely, the control system, throttle method, throttle actuator, injector, reactor and nozzle. The resultant compilation of possible designs is shown in Table 1. Advantages and disadvantages for each of these design variants were tabulated.

From this compilation, a matrix of ninety potential systems was selected. These systems were compared on the basis of estimated mission performance, concept feasibility and development required as detailed in Table 2. The resultant matrix and ratings are shown in Table 3. While a ranking of this sort is admittedly imperfect, it does serve to identify the more interesting combinations.

The selected systems are indicated in Table 3. Each thruster system consists of reactor/bed selection and a reactor/nozzle choice and therefore two callouts are required. In addition to the previously stated design concept selection criteria, an attempt was made to include alternate approaches by including a member from each row and column of the tradeoff matrix. The selected thruster system design concepts are summarized in Table 4. The remainder of Phase I will consist of detailed studies of these systems only.

B. Design Studies

The design study effort has three parts: System Performance Studies, Flow Control Studies and Preliminary Designs.

Table 1. Potential Design Concepts

CONTROL SYSTEMS

POSITION FEEDBACK
CHAMBER PRESSURE FEEDBACK
GUIDANCE LOOP SENSING (h , \dot{h} , \ddot{h})

ACTUATORS

ELECTRO-MECHANICAL
ELECTRO-HYDRAULIC
ELECTRO-PNEUMATIC
ELECTRO-FLUIDIC
FLUIDIC-HYDRAULIC
FLUIDIC-PNEUMATIC

THROTTLING METHODS

UPSTREAM VALVING - INCREMENTAL OR CONTINUOUS
INJECTOR VALVING - INCREMENTAL OR CONTINUOUS
UPSTREAM PLUS INJECTOR VALVING - INCREMENTAL OR CONTINUOUS
VARIABLE AREA THROAT PLUS INJECTOR VALVING - CONTINUOUS

THROTTLE VALVES

LINEAR PLUG - CAVITATING, NON-CAVITATING OR COMBINATION
BALL
ROTARY PLUG
BLADE
SLIDE
FLAPPER
SPOOL

INJECTORS

SPUD - SWIRL NOZZLES, IMPINGING SHEETS, IMPINGING JETS,
MULTI JETS, WOVEN WIRE
SHEET - CIRCULAR SLOTS, LAMINATIONS
SHOWERHEAD - PARALLEL JETS, WOVEN WIRE

REACTOR TYPES

CATALYTIC
THERMAL WITH CATALYTIC PILOT

REACTOR GEOMETRIES

CYLINDRICAL
SPHERICAL
ANNULAR

NOZZLES

DELAVAL
SPIKE OR AEROSPIKE
EXPANSION DEFLECTION

Table 2. Design Concept Selection Criteria

CONCEPT FEASIBILITY

WHAT IS THE INTRINSIC FEASIBILITY OF THE DESIGN CONCEPT?
THIS JUDGEMENT TO BE INDEPENDENT OF THE CONCEPTS CURRENT
DEVELOPMENT STATUS.

MISSION PERFORMANCE

WHAT IS ESTIMATED RANKING OF CONCEPTUAL SYSTEMS IN
TERMS OF TOTAL PROPULSION SYSTEM WEIGHT FOR A TYPICAL MARS
LANDER MISSION? HOW IS THE RANKING AFFECTED BY THRUST LEVEL?

DEVELOPMENT REQUIRED

HOW MUCH DEVELOPMENT IS NEEDED TO MAKE THE CONCEPT
AN OPERATIONAL REALITY?

ALTERNATE APPROACH REPRESENTATION

AT LEAST ONE MEMBER FROM EACH ROW AND COLUMN OF
THE TRADEOFF MATRIX WAS INCLUDED.

Table 3. Thrustor System Comparison Chart

DEVELOPMENT REQUIRED: SA = State of Art MD = Moderate Development ED = Extensive Development
 CONCEPT FEASIBILITY: QF = Questionable Feasibility RF = Relatively Feasible HF = Highly Feasible
 ESTIMATED PERFORMANCE RANKING: 1-10 10 = High Performance 1 = Low Performance

REACTOR CONCEPT	FLOW CONTROL CONCEPT						NOZZLE CONCEPT		
	CAVITATING VENTURI		NON-CAVITATING VENTURI		FLOW CONTROL INJECTOR		DE LAVA	SPIKE	EXPANTR DEF BUTT
	FIXED AREA INJECTOR	VARIABLE LOSS INJECTOR	FIXED AREA INJECTOR	VARIABLE LOSS INJECTOR	FLOW CONTROL INJECTOR	AREA NOZZLE			
Catalytic Cylindrical	SA ① HF 5	MD RF 5	SA ② RF 5	MD RF 5	MD RF 7	ED RF 8	SA ③ HF 5	MD HF 7	ED RF 6
	ED ④ RF 4	ED QF 3	ED RF 4	ED QF 3	ED QF 6	ED QF 7	MD QF 3	MD HF ④ 7	ED QF 6
Annular	MD RF 7	MD QF 7	MD RF ⑧ 7	MD RF 7	ED RF ⑤ 8	ED QF 9	SA HF ⑤ 5	MD QF 6	ED RF ⑤ 9
	MD QF 6	MD HF ⑥ 6	MD QF 6	MD RF 6	MD RF 8	ED RF ③ 9	SA QF ⑥ 5	SA HF 6	ED HF ⑤ 8
Thermal Decomposition Cylindrical	MD QF 5	MD HF 5	MD QF ⑤ 5	MD RF ⑦ 5	ED RF 7	ED QF 8	SA QF 5	MD HF ⑦ 7	ED QF 6
	MD QF 5	MD HF 5	MD QF ⑤ 5	MD RF ⑦ 5	ED RF 7	ED QF 8	SA QF 5	MD HF ⑦ 7	ED QF 6

Table 4. Selected Design Concepts

NUMBER	DESCRIPTION
1	CYLINDRICAL CATALYTIC BED, FIXED AREA INJECTOR, CAVITATING VENTURI FLOW CONTROL, DELAVAL NOZZLE
2	CYLINDRICAL CATALYTIC BED, FIXED AREA INJECTOR, NON-CAVITATING VENTURI FLOW CONTROL, DELAVAL NOZZLE
3	CYLINDRICAL CATALYTIC BED, FLOW CONTROL INJECTOR, VARIABLE AREA EXPANSION-DEFLECTION NOZZLE
4	ANNULAR CATALYTIC BED, FIXED AREA INJECTOR, CAVITATING VENTURI FLOW CONTROL, SPIKE NOZZLE
5	SPHERICAL CATALYTIC BED, FLOW CONTROL INJECTOR, EXPANSION DEFLECTION NOZZLE
6	CYLINDRICAL THERMAL DECOMPOSITION BED, VARIABLE LOSS INJECTOR, CAVITATING VENTURI FLOW CONTROL, DELAVAL NOZZLE
7	ANNULAR THERMAL DECOMPOSITION BED, VARIABLE LOSS INJECTOR, NON-CAVITATING VENTURI FLOW CONTROL, SPIKE NOZZLE
8	SPHERICAL CATALYTIC DECOMPOSITION BED, FIXED AREA INJECTOR, NON-CAVITATING VENTURI FLOW CONTROL, DELAVAL NOZZLE
9	CYLINDRICAL THERMAL DECOMPOSITION BED, FLOW CONTROL INJECTOR, VARIABLE AREA EXPANSION-DEFLECTION NOZZLE

1. System Performance Studies

The following recommended assumptions for the system performance studies were reviewed and accepted by the JPL technical manager.

- a. Thrust will be considered a parameter and levels between 300 lbf and 1200 lbf will be considered.
- b. The total propulsion system mass will be the central measure of system performance.
- c. A constant percent thrust versus time duty cycle will be used for each thrust level, Figure 1. (An analysis was performed to show that the thrust to mass ratio which maximizes payload is very nearly independent of vehicle size. The assumption of a constant percent thrust versus time is equivalent to a constant thrust to mass ratio; i.e., the propulsion system total impulse is directly proportional to vehicle size.)
- d. A 2:1 pressure-ratio, blowdown pressurization system using nitrogen gas will be employed. The schematic will be as shown in Figure 2.
- e. The ambient pressure will be constant at 0.3 psia throughout the duty cycle. (Since the ignition altitude is on the order of a few km, only a negligible ambient pressure variation will occur.)
- f. Annealed 6 Al-4V titanium tankage with a safety factor of 2.2 will be used. Positive propellant expulsion is not required.
- g. The effects of variable chamber pressure and expansion ratio will be considered. Conceptually at least, optimized values yielding minimum propulsion system weight for these variables will be selected.
- h. A minimum gage thickness of 0.015" will be used for both tankage and engine components.

The governing equations for the system weight have been written and programming of these equations for an on-line computer is in process. Computation of thrust chamber weights and performance for the nine systems as a function of F , P_c , ϵ and chamber design was underway at the end of the reporting period.

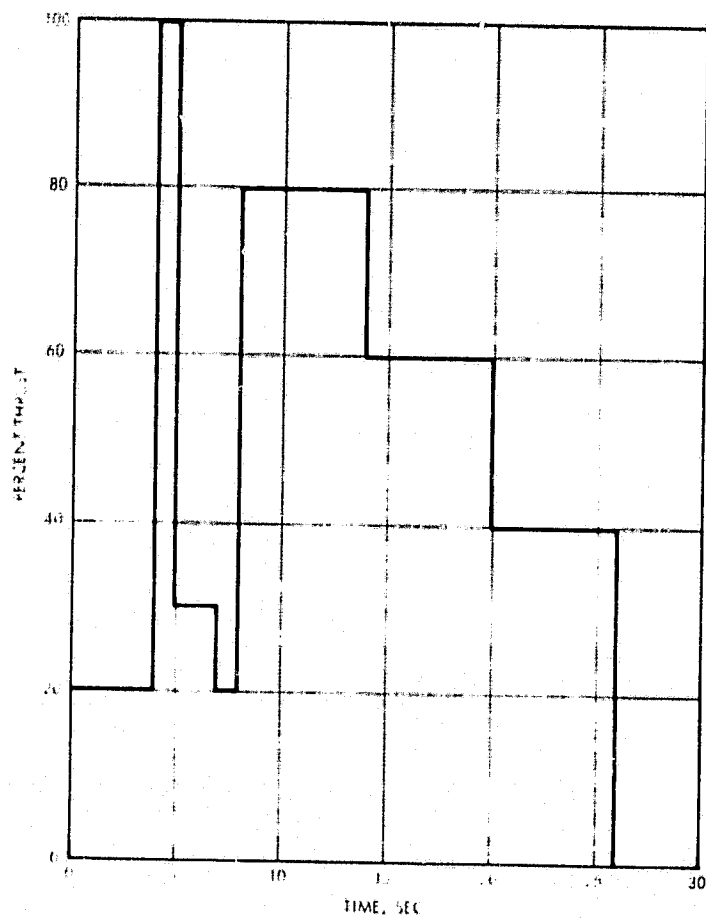


Figure 1. Model Duty Cycle Percent Thrust vs. Time

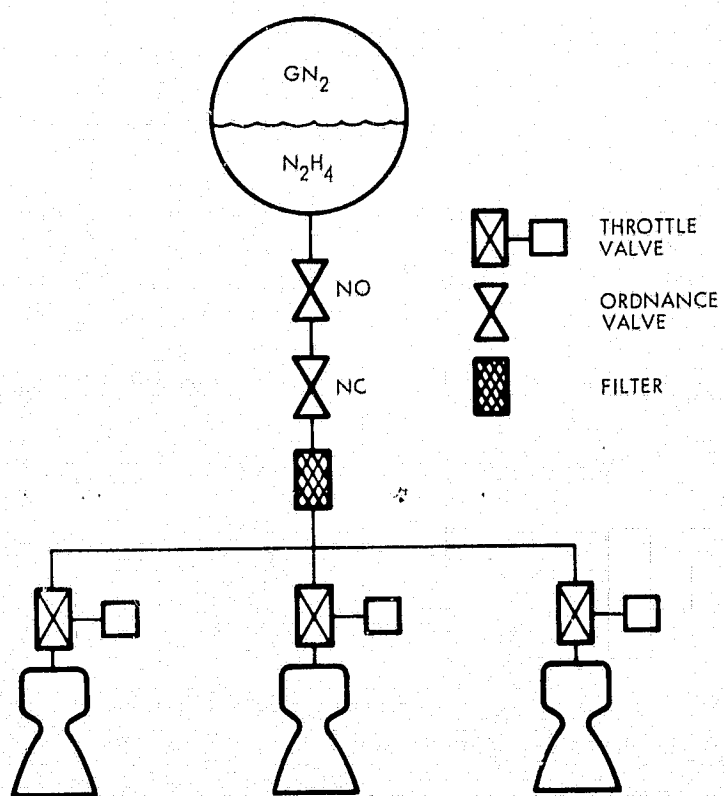


Figure 2. Model System Schematic

2. Flow Control

Studies will be completed in the following areas: Throttle Mechanizations, Throttle Valve Performance (pressure drop, accuracy and dynamic considerations), Throttle Actuator (response and design variations) and Control Systems (accuracy, response and stability). These studies were in process at the end of the reporting period.

3. Preliminary Designs

A preliminary design study will be completed for each of the nine systems. A thrust level of 600 lbf has been selected for these studies. A weight breakdown will be prepared for each of these designs and used as a baseline in the determination of thruster weight computations mentioned above in paragraph II.B-1.

III. CONCLUSIONS AND RECOMMENDATIONS

This report covers the first two months of the three month, Phase I Study and Analysis; consequently, no conclusions or recommendations of substance regarding the future phases of the program can be made at this time. It is intended that the next Quarterly Progress Report will be a Summary Report for the Phase I study.

IV. NEW TECHNOLOGY

Several of the concepts under study are regarded as new technology. Reports covering four such items are under preparation and will be included in the next Quarterly Progress Report.